

DEVELOPMENT OF A DC-DC BUCK BOOST CONVERTER USING FUZZY  
LOGIC CONTROL

FATHI SHABAN JABER

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Universiti Tun Hussein Onn Malaysia

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## ABSTRACT

A fuzzy controller of DC-DC Buck-boost converter is designed and presented in this project. In order to control the output voltage of the buck-boost converter, the controller is designed to change the duty cycle of the converter. The mathematical model of buck-boost converter and fuzzy logic controller are derived to design simulation model. The simulation is developed on Matlab simulation program. To verify the effectiveness of the simulation model, an experimental set up is developed. The buck-boost circuit with mosfet as a switching component is developed. The fuzzy logic controller to generate duty cycle of PWM signal is programmed. The simulation and experimental results show that the output voltage of the buck-boost converter can be controlled according to the value of duty cycle

## ABSTRAK

Sebuah pengawal alat peranti fuzzy Buck-boost DC-DC direka dan dihasilkan dalam projek ini. Untuk mengendalikan tegangan output dari alat peranti *buck-boost*, alat pengawal direka untuk menukar kerja-kerja kitaran dari alat peranti. Model matematik dari peranti *buck-boost* dan pengawal *logic fuzzy* yang diperolehi dan direka digunakan sebagai model simulasi. Simulasi dibangunkan dalam program *Matlab*. Untuk menunjukkan hasil keberkesanan yang sebenar, sebuah peranti eksperimental dibangunkan. Rangkaian *buck-boost* beserta dengan *mosfed* dibangunkan sebagai komponen pertukaran pengawal *logic -fuzzy* untuk menghasilkan kerja-kerja kitaran dari isyarat PWM yang telah diprogramkan. Simulasi dan hasil percubaan menunjukkan bahawa voltan keluaran dari peranti *buck-boost* boleh dikawal sesuai dengan nilai kitaran kerja.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Project background

Nowadays, fuzzy logic controllers have been used in many industrial applications and also power electronic drives in order to improve performance without having to develop mathematical model of the system. The main feature of a fuzzy controller is that it can convert the linguistic control rules based on expert knowledge into automatic control strategy. So it can be applied to control systems with unknown or unmodelled dynamics. (Ozdemir, 1997)

General idea of dc-dc converter to convert a fixed voltage dc source into a variable voltage dc source. The output voltage of the dc-dc converter can be higher or lower than the input. Dc-Dc Converter widely used for traction motor in electric automobiles, trolley cars, marine hoists, and forklift trucks. They provide smooth acceleration control, high efficiency, and fast dynamic response. Dc converter can be used in regenerative braking of dc motor to return energy back into the supply, and this feature results in energy saving for transportation system with frequent stop; and also are used, in dc voltage regulation. There are many types of dc-dc converter which is buck (step down converter, boost (step-up) converter, and buck-boost (step up- step-down) convertor. (Muhammad H. Rashid, 2004)

Buck Boost converter is an intriguing subject from the control point of view, due to its intrinsic non-linearity. Common control approaches like voltage control and current injected control, require a good knowledge of the system and accurate tuning in order to obtain performances.

The fuzzy logic approach has been proposed to converters. Its major advantage is that expert knowledge can regulate the output voltage of the switching DC–DC Buck boost converter be incorporated into the fuzzy controller using simple linguistic rules to achieve the control objective without involving the converter's mathematical models. (SO W.C., 1996) and (LIN P.Z., 2006) The Fuzzy logic controller are designed based on dimensional rule table using voltage error and change in voltage error as input variables and change in duty cycle as control output. (S. Arulselvi, 2005)

## 1.2 Problem Statements

Development of the DC-DC Converter requires PWM signals with a high switching frequency to avoid more of output voltage ripple. In this project the problem statements are how to develop simulation model of buck-boost converter and fuzzy logic controller and also how to develop hardware of buck-boost converter and fuzzy logic controller to control duty cycle of PWM signal generator

## 1.3 Objectives of the Project

The major objectives of this research are.

- 1- To develop modelling variable DC output voltage using MATLAB fuzzy logic controller for Buck boost converter.
- 2- To develop Hardware of fuzzy logic controller for variable output voltage DC-DC Buck boost converter.

## **1.4 Scopes of the project**

### **1.4.1 Simulation Scopes on MATLAB**

Simulation consists of -:

- a) Modelling DC to DC converter.
- b) Modelling fuzzy logic controller.

### **1.4.2 Hardware Scopes**

Hardware scope consists of-:

- a) Develop DC-DC converter.
- b) Develop fuzzy logic controller on DSP board.
- c) Develop variable output voltage fuzzy logic controller of a DC-DC Buck boost converter

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

Fuzzy logic is a powerful problem solving methodology introduced by Lotfi Zadeh in 1965's. Fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions.

Nowadays, FLC applications are successfully used in many fields including automatic focus cameras, household materials such as dishwashers, automobile industry etc.

#### **2.2 DC-DC Convertors**

In many industrial applications, it is required to convert a fixed-voltage dc source into a variable-voltage dc source. A dc-dc converter converts directly from dc to dc and is simply known as a dc converter. A dc converter can be considered as dc equivalent to an ac transformer with continuously variable turns ratio. Like transformer, it can be used to step down or step up a dc voltage source. (Muhammad H. Rashid, 2004)

Dc converters widely used for traction motor in electric automobiles, trolley cars, marine hoists, and forklift trucks. They provide smooth acceleration control, high efficiency, and fast dynamic response. Dc converter can be used in regenerative braking of dc motor to return energy back into the supply, and this feature results in energy

saving for transportation system with frequent stop; and also are used, in dc voltage regulation. There are many types of DC-DC convertor which is buck (step down) converter, boost (step-up) converter, buck-boost (step up- step-down) convertor. (Muhammad H. Rashid, 1993)

DC conversion is of great importance in many applications, starting from low power applications to high power applications. The goal of any system is to emphasize and achieve the efficiency to meet the system needs and requirements. Several topologies have been developed in this area, but all these topologies can be considered as apart or a combination of the basic topologies which are buck, boost and flyback (Rashid, M. H., 2007)

For low power levels, linear regulators can provide a very high-quality output voltage. For higher power levels, switching regulators are used. Switching regulators use power electronic semiconductor switches in On and Off states.

Because there is a small power loss in those states (low voltage across a switch in the on state, zero current through a switch in the off state), switching regulators can achieve high efficiency energy conversion.

### **2.2.1 Functions of DC-DC converters**

The DC-DC converter has some functions. These are:

- i. Convert a DC input voltage  $V_s$  into a DC output voltage  $V_o$ .
- ii. Regulate the DC output voltage against load and line variations.
- iii. Reduce the AC voltage ripple on the DC output voltage below the required level.
- iv. Provide isolation between the input source and the load (if required).
- v. Protect the supplied system and the input source from electromagnetic interference (Rashid, M. H., 2007)

The DC-DC converter is considered as the heart of the power supply, thus it will affect the overall performance of the power supply system. The converter accepts DC and produces a controlled DC output.

### 2.3 Buck-boost converter

A buck-boost converter provides an output voltage that may be less than or greater than the input voltage hence the name ‘buck-boost’; the output voltage polarity is opposite to that of the input voltage. This converter is also known as an inverting regulator. The circuit arrangement of a buck-boost converter is shown in figure 2. 1:

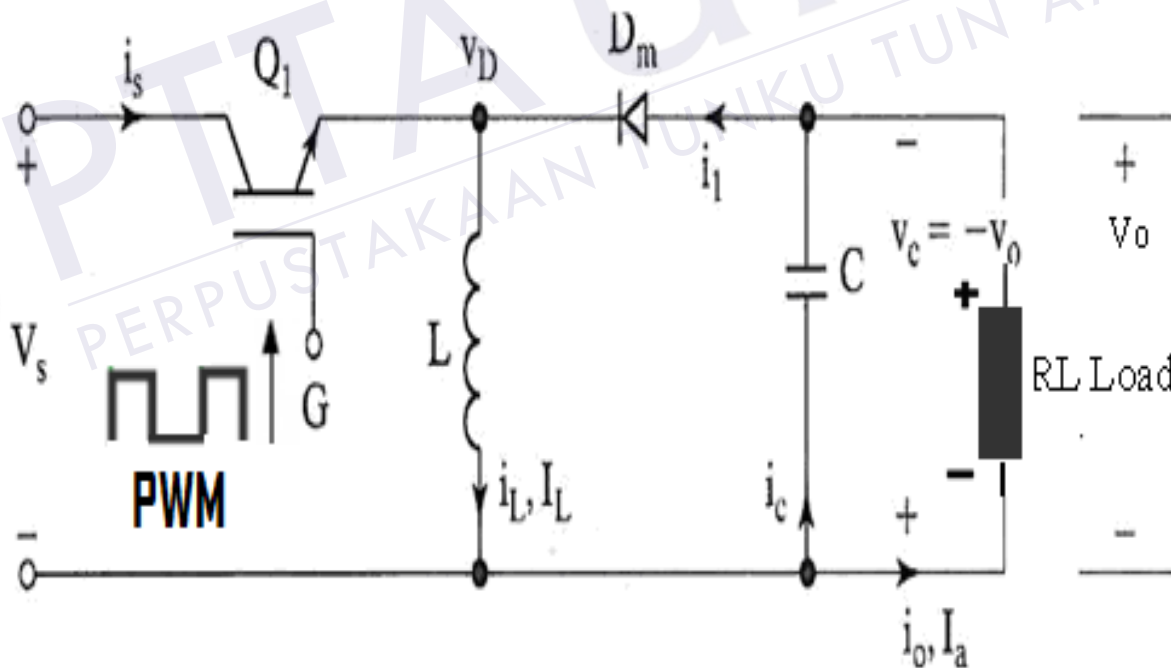


Figure 2.1: buck-boost converter diagram

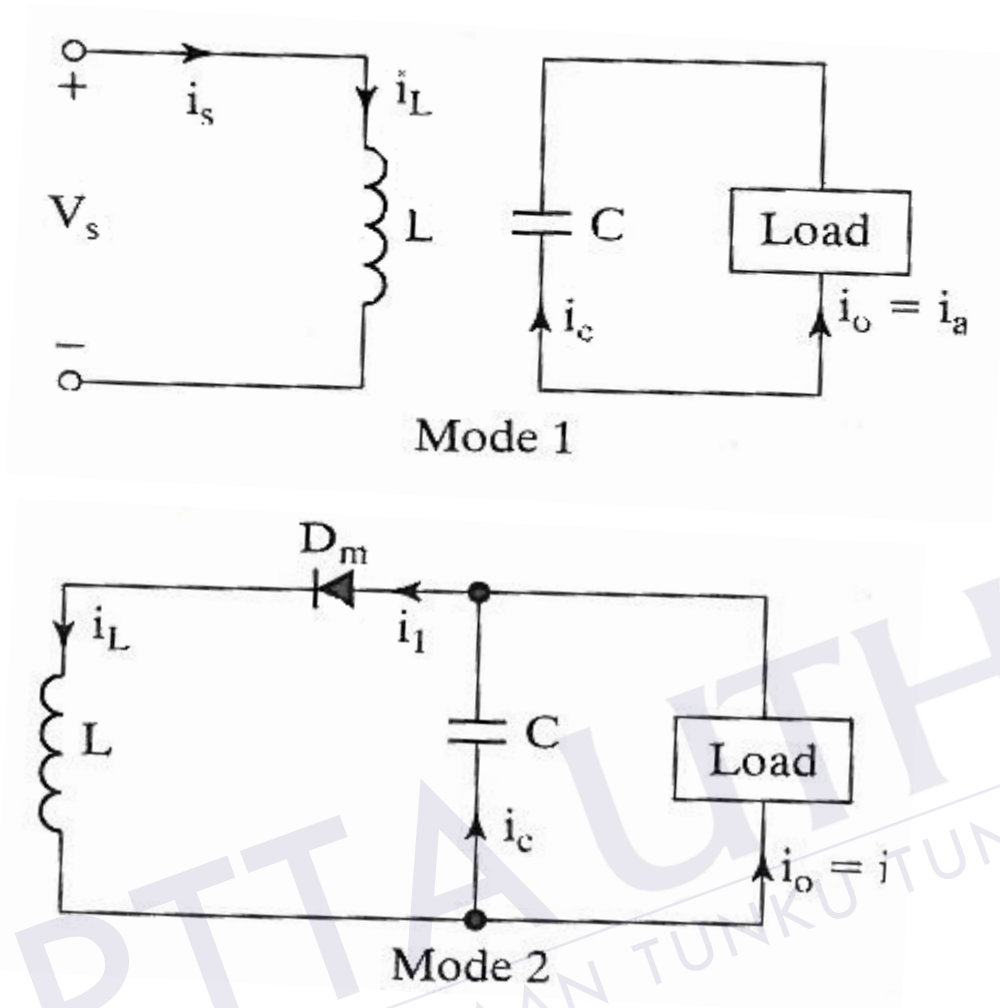


Figure 2.2: equivalent circuits of Buck boost converter

The circuit operation divided into two modes. During mode 1, transistor Q1 is turned on and diode Dm is reversed biased. The input current, which rises, flows through inductor L and transistor Q1. During mode 2, transistor Q1 is switched off and the current, which was flowing through inductor L, would flow through L, C, Dm, and the load. The energy stored in inductor L would be transferred to the load and inductor current would fall until transistor Q1 is switched on again in the next cycle. The equivalent circuit for the modes are shown in figure 2.2. The wave-forms for steady-state voltages and currents of buck boost converter are shown in Figure 2.3:



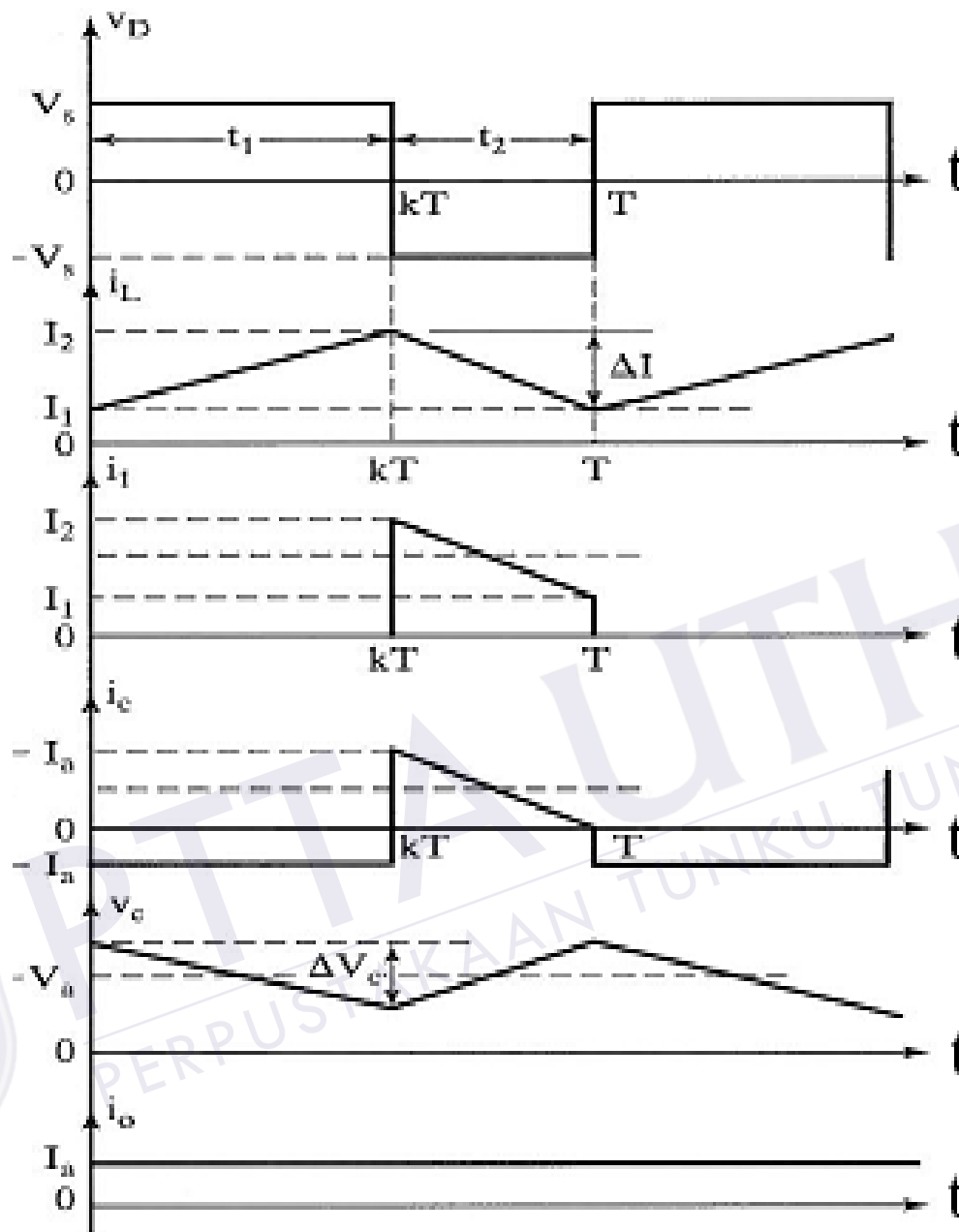


Figure 2.3: waveforms of buck boost converter

The rate of change of inductor current is a constant, indicating a linearly increasing inductor current. The preceding equation can be expressed as

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s}{L} \quad (2.1)$$

Solving for  $\Delta i_L$  when the switch is closed

$$(\Delta i_L)_{closed} = \frac{V_s DT}{L} \quad (2.2)$$

Analysis for the switch open. When the switch is open; the current in the inductor cannot change instantly, resulting in a forward-biased diode and current into the resistor and capacitor. In this condition, the voltage across the inductor is

$$v_L = V_O = L \frac{di_L}{dt} \quad (2.3)$$

$$\frac{di_L}{dt} = \frac{V_O}{L} \quad (2.3)$$

Again the rate of change of inductor current is constant, and the change in current is

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_O}{L} \quad (2.4)$$

Solving for  $\Delta i_L$ ,

$$(\Delta i_L)_{open} = \frac{V_O(1-D)T}{L} \quad (2.5)$$

For steady-state operation, the net change in inductor current must be zero over one period using Eqs.2.2 and 2.5,

$$(\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0$$

$$\frac{V_s DT}{L} + \frac{V_O(1-D)T}{L} = 0 \quad (2.6)$$

Solving for  $V_O$ ,

$$V_O = -V_s \left[ \frac{D}{1-D} \right] \quad (2.7)$$

Equation 2.7 shows the output voltage has opposite polarity from the source voltage. Output magnitude of the buck boost converter can be less than the source greater than the source, depending on the duty ratio of the switch. If  $D > 0.5$ , the output is larger than the input, and if  $D < 0.5$ , output is smaller than the input.

Note that the source is never connected directly to the load in the buck boost converter. Energy is stored in the inductor when the switch is closed and transferred to the load when switch is open. Hence, the buck boost converter is also referred to as an indirect converter.

Power absorbed by the load must be the same as that supplied by the source,

where

$$P_O = \frac{V_O^2}{R} \quad (2.8)$$

$$P_S = V_S I_S \quad (2.9)$$

$$\frac{V_O^2}{R} = V_S I_S \quad (2.10)$$

Average source current is related to average inductor current by

$$I_S = I_L D$$

Resulting in

$$\frac{V_O^2}{R} = V_S I_L D \quad (2.11)$$

Substituting for  $V_O$  using Eeq 2.7 and solving for

$$I_L = \frac{V_O^2}{V_S D R} = \frac{P_O}{V_S D} = \frac{V_S D}{R(1-D)^2} \quad (2.12)$$

Maximum and minimum inductor current is determined using Eeq 2.2 and 2.12

$$I_{max} = I_L + \frac{\Delta i_L}{2} = \frac{V_S D}{R(1-D)^2} + \frac{V_S D T}{2L} \quad (2.13)$$

$$I_{min} = I_L - \frac{\Delta i_L}{2} = \frac{V_S D}{R(1-D)^2} + \frac{V_S D T}{2L} \quad (2.14)$$

For continuous current, the inductor current must remain positive. To determine the boundary between continuous and discontinuous current  $I_{min}$  is set to zero in Eqs 2.14,

$$(LF)_{min} = \frac{(1-D)^2 R}{2} \quad (2.15)$$

Or

$$L_{min} = \frac{(1-D)^2 R}{2f} \quad (2.16)$$

When  $F$  is switching frequency in hertz

### Output voltage ripple

The output voltage ripple for the buck boost converter is computed from the capacitor current waveform

$$|\Delta Q| = \left(\frac{V_O}{R}\right) DT = C \Delta V_O \quad (2.17)$$

Solving for  $\Delta V_O$ ,

$$V_O = \frac{V_O DT}{RC} = \frac{V_O D}{RCF} \quad (2.18)$$

$$\frac{\Delta V_O}{V_O} = \frac{D}{RCF} \quad (2.19)$$

## 2.4 Fuzzy Logic Controller

Fuzzy Logic Controller (FLC) is constitutes a way of converting linguistic control strategy into an automatic by generating a rule base which controls the behaviour of the system. Fuzzy control is control method based on fuzzy logic. Fuzzy provides a remarkably simple way to draw definite conclusions from vague ambiguous or imprecise

information. It suitable for applications such as the speed control of dc motor which is has non linearities. (Siler, W. and Ying, H, 1989)

FLC have some advantages compared to other classical controller such as simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic incorporates an alternative way of thinking which allows modelling complex systems using higher level of abstraction originating from the knowledge and experience. Fuzzy logic can be described simply as computing words rather than numbers” or “control with sentence rather than equations.” (Siler, W. and Ying, H, 1989)

The applications of fuzzy logic are usually for household appliance such as washing machine and rice cooker. Fuzzy also been used in industrial process such as cement kilns, underground trains and robots.

## 2.5 Structure of Fuzzy Logic

Structure of a fuzzy logic controller consists of: input, fuzzification, Rule base, Defuzzification, output. There are specific components characteristic of a fuzzy controller to support a design procedure. Figure 2.4. Shows the controller between the input and output. (Jan Jantzen 1998)

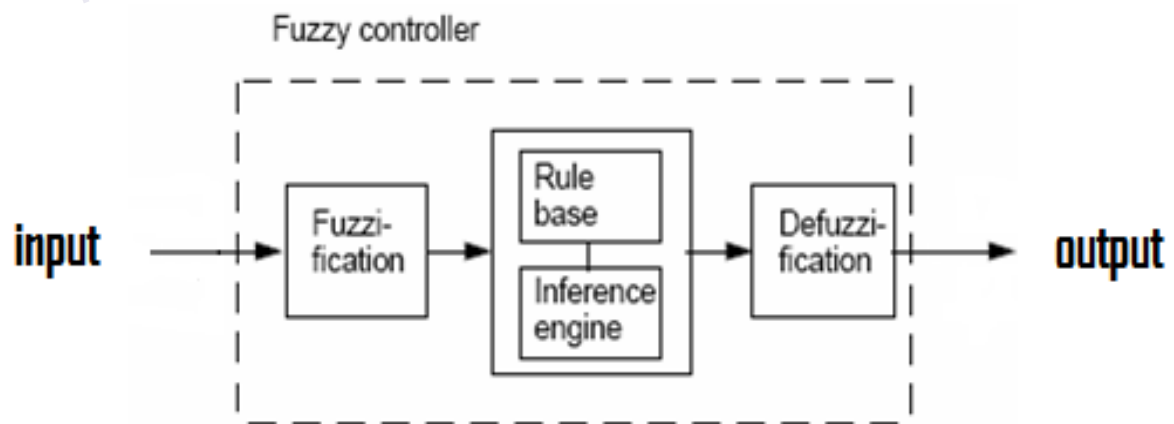


Figure 2.4: Structure of fuzzy logic controller

### **2.5.1 Input**

The inputs are most often hard or crisp measurement from some measuring equipment is converted into fuzzy values for each input fuzzy set with the fuzzification block. (Jan Jantzen 1998)

### **2.5.2 Fuzzification**

The first block inside the controller is fuzzification which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block matches the input data with the conditions of the rules to determine. There is degree of membership for each linguistic term that applies to the input variable. (Jan Jantzen 1998)

### **2.5.3 Rule Base**

The collection of rules is called a rule base. The rules are in “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error ( $e$ ) and change in error ( $de$ ). In a rule based controller the control strategy is stored in a more or less natural language. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques. (Jan Jantzen 1998)

### **2.5.4 Defuzzification**

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system.

The output levels are depending on the rules that the systems have and the positions depending on the non-linearities existing to the systems. To achieve the result, develop the control curve of the system representing the I/O relation of the systems and based on the information; define the output degree of the membership function with the aim to minimize the effect of the non-linearity (Jan Jantzen 1998)

### 2.5.5 Output

The output is output gain that can be tuned and also become as an integrator .The output crisp value can be calculated by the centre of gravity or the weighted average [7]

### 2.6 eZdsp<sup>TM</sup> F2808 board

The eZdsp<sup>TM</sup> F2808 is a stand-alone card--allowing evaluators to examine the TMS320F2808 digital signal processor (DSP) to determine if it meets their application requirements. Furthermore, the module is an excellent platform to develop and run software for the TMS320F2808 processor.

The eZdsp<sup>TM</sup> F2808 is shipped with a TMS320F2808 DSP. The eZdsp<sup>TM</sup> F2808 allows full speed verification of F2808 code. Expansion connectors are provided for any necessary evaluation circuitry not provided on the as shipped configuration.

To simplify code development and shorten debugging time, a C2000 Tools Code Composer driver is provided. In addition, an onboard JTAG connector provides interface to emulators, operating with other debuggers to provide assembly language and 'C' high level language debug. (Texas Instruments 2007) A photograph of the eZdsp<sup>TM</sup> F2808 board is shown in Figure: 2.5.

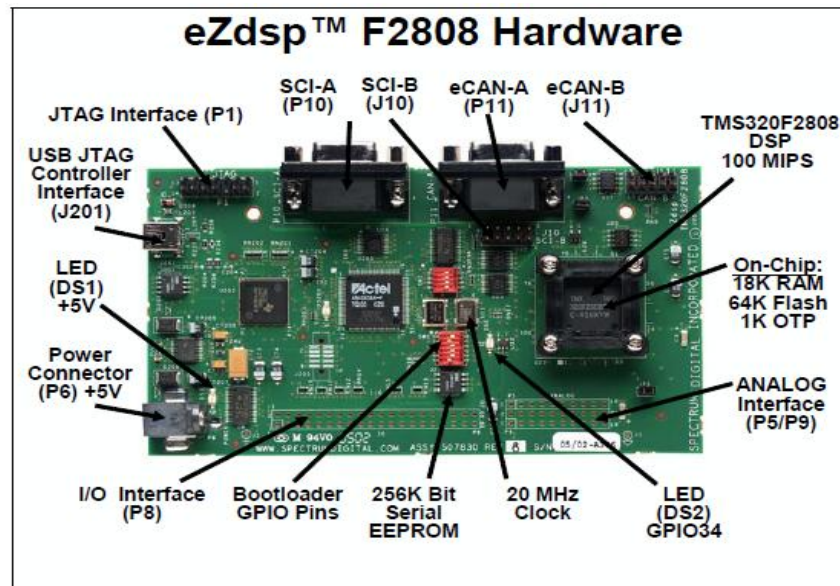


Figure: 2.5: eZdsp™ F2808 board

### 2.6.1 Key Features of the eZdsp™ F2808

The eZdsp™ F2808 has the following features:

- TMS320F2808 Digital Signal Processor
- 100 MIPS operating speed
- 18K words on-chip zero wait state SARAM
- 64K words on-chip Flash memory
- 256K bits serial I2C EEPROM memory
- 20 MHz. clock
- Expansion Connectors (analog, I/O)
- Onboard IEEE 1149.1 JTAG Controller
- 5-volt only operation with supplied AC adapter
- TI F28xx Code Composer Studio tools driver
- On board USB JTAG emulation connector
- 2 SCI UART channels
- 2 eCAN channels.



## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 Introduction**

This chapter discusses the software and hardware development and implementation of the project and procedures that are being used to develop the project including the equipment, tools and processes used in the software and hardware development and implementation of the project. The methodology process utilizes both software simulation and hardware construction. It is virtual to simulate the system by using software to get the theoretical result before hardware designation can be made. The selection of component for the hardware is also important in order to reduce cost, increase the system efficiency and increase reliability of the circuit.

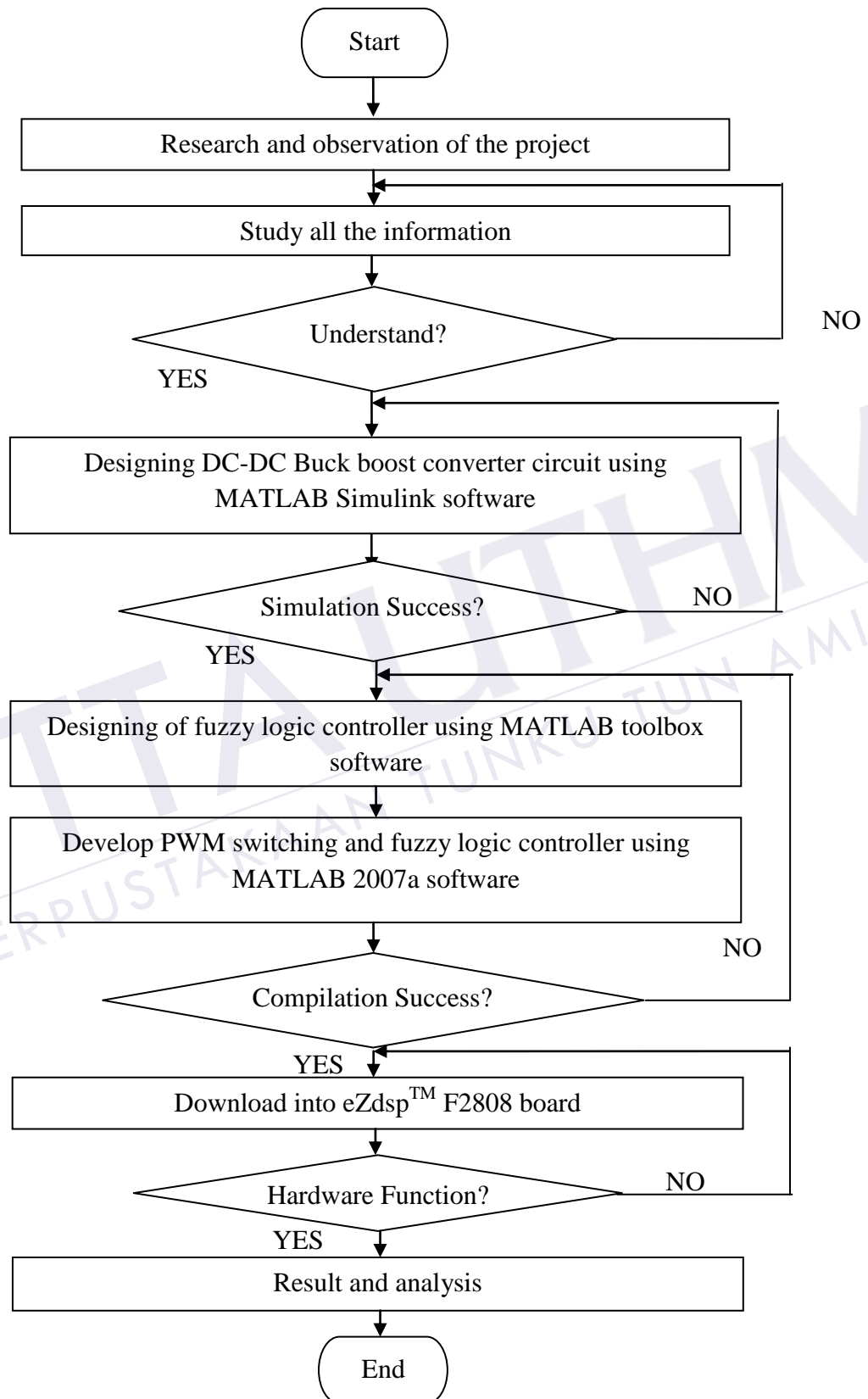


Figure 3.1: Flowchart of project

The Comprehensive planning of this project is shown in Figure 3.1. The flowchart of this project was begin by doing some research and observation based on the previous research especially the information related with the applications of PWM generation and Fuzzy logic controller technique. The next stage is to do the simulation of DC-DC Buck boost converter by using Matlab Simulink software. After doing this simulation circuit part, the next stage is the programming of Fuzzy logic controller using Matlab toolbox. Finally, generated code of PWM switching pulses and controller using real time workshop on Matlab Simulink software to download into eZdsp<sup>TM</sup> F2808 board and connected with the gate driver circuit and buck boost converter circuit. The output of converter is analyzed in term of number of pulse signals and output voltage.

### 3.2 Proposed design

In order to control the DC output voltage of buck boost converter and to ensure good variable output voltage the fuzzy logic controller for closed loop control of DC -DC Buck boost convertor proposed in this project.

Figure 3.2.Shows the block diagram of the proposed system. The system consists of dc-dc buck boost converter to maintain dc voltage. A sensor is used to sense the output voltage and which is used for voltage feedback. A digital signal processor is employed to generate Fuzzy logic controller and PWM signal to switch the dc-dc buck boost converter.

In the voltage control loop, the actual voltage ( $V_o$ ) is sensed by sensor and the error signal is obtained by comparing with reference voltage ( $V_{ref}$ ). From the present error and pervious error the change in error is calculated

In the proposed system two input fuzzy controllers are used. The error and change in error are given as inputs to the fuzzy logic controller. The output of the fuzzy controller is denoted as duty cycle.

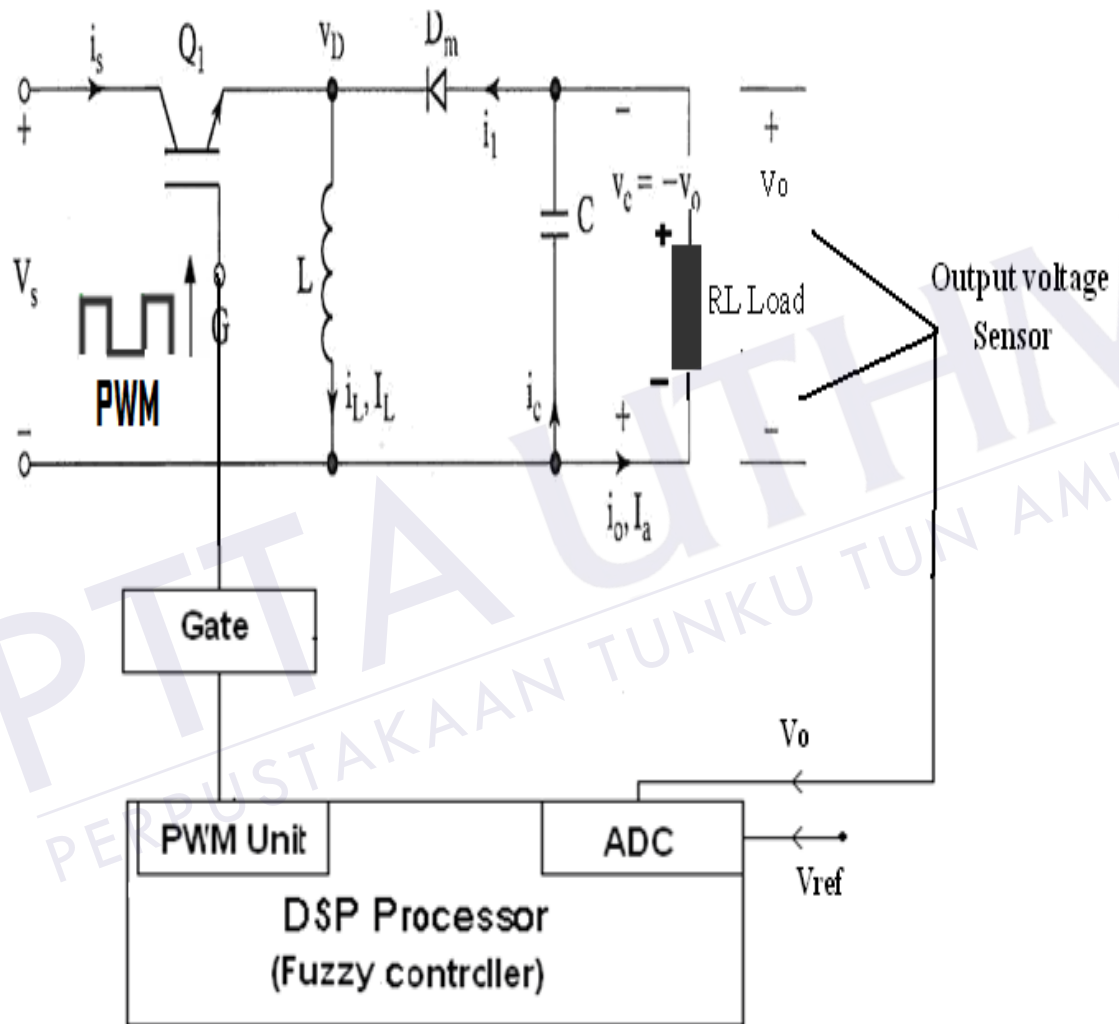


Figure 3.2: Block diagram of the proposed system

### 3.2 Fuzzy logic controller for proposed system

In Fuzzy logic system the linguistic variables are used instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) in to a linguistic variable (fuzzy number or fuzzy variable) is called fuzzification.

In this work, the dc voltage converter variables are voltage. The output voltage is controlled by Fuzzy logic controller. The error  $e(k)$  and change in error  $\Delta e(k)$  is given as input to the Fuzzy logic controller. The error is found by comparing the actual voltage  $V_o(k)$  with reference voltage  $V_{rf}(k)$ . From the error  $e(k)$  and previous error  $E_{previous}(k)$  the change in error is calculated and then it is normalized, in order to use the same fuzzy logic controller for different reference voltage. Then the error and Change in error are fuzzified (Adel E. El-kholy and A. M. Dabroom, 2002) given in equations (3.1) and (3.2)

$$e(k) = V_{rf}(k) - V_o(k) \quad (3.1)$$

$$\Delta e(k) = e(k) - E_{previous}(k) \quad (3.2)$$

Five linguistic variables are used for the input variable  $e(k)$  and  $\Delta e(k)$ . That are negative big (NB), negative small (NS), zero (Z), positive small (PS) and positive big (PB). There are many types of membership functions, such as triangular-shaped, Gaussian, sigmoid, pi-shaped trapezoidal- shaped, bell-shaped etc. the Gaussian membership function is used for simplicity and also to reduce the calculations. (N Senthil Kumar, 2007). Normally seven membership functions are preferred for accurate result. In this work only five membership functions are used for the input, error and change in error. In order to reduce the number of membership function the width of the membership functions are kept different. The membership function width for the center membership functions is considered narrow and wide towards outer. The input fuzzy membership functions are shown in Figure 3.3, 3.4.

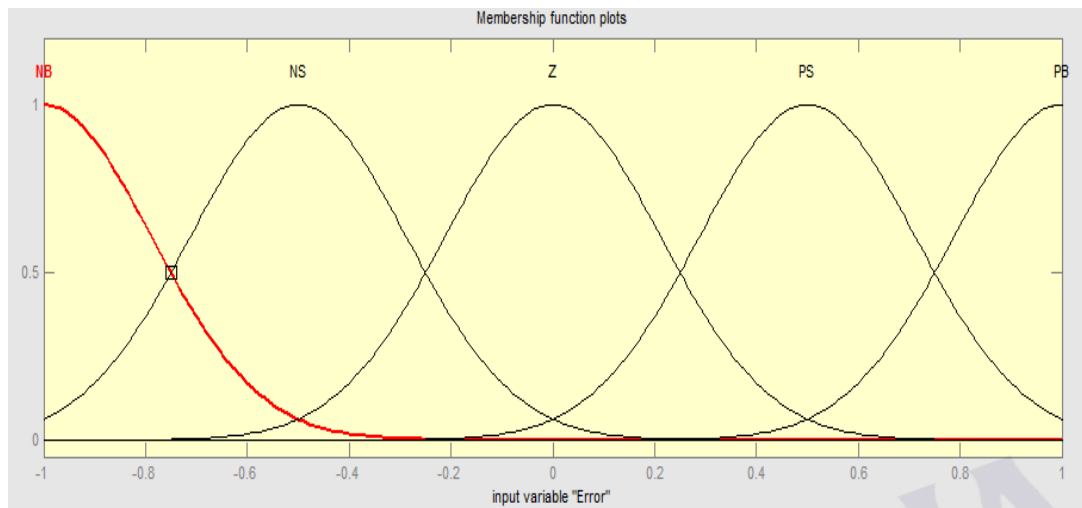


Figure 3.3: Error (input)

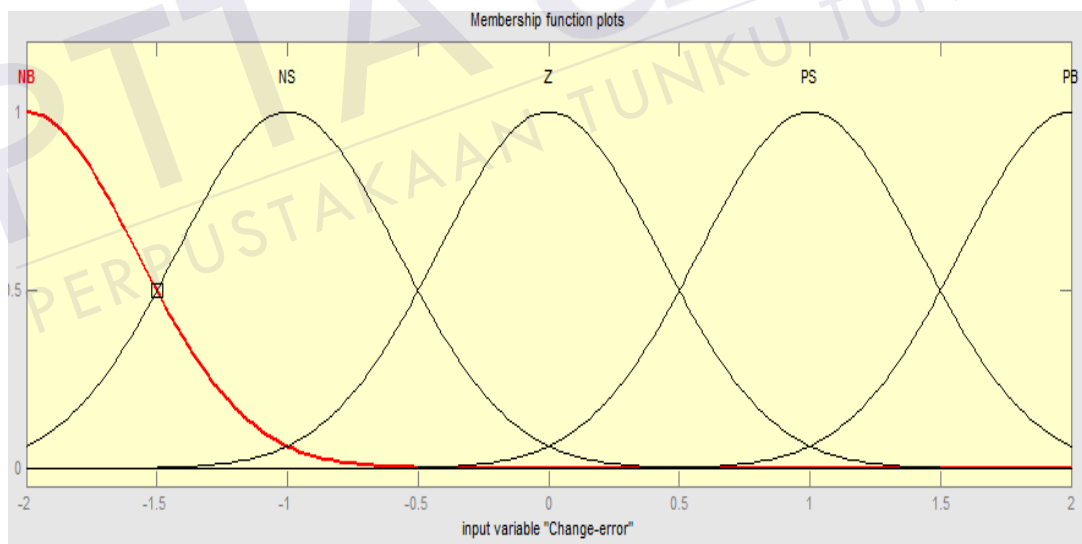


Figure 3.4: Change in Error (input)

The control rules that relate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior, also the perception and experience.

However, some of the control rules are developed using “trial and error” method.

(T.Gupta & R.Boudreax, 1997)

The general rule can be written as

If  $e(k)$  is  $X$  and  $\Delta e(k)$  is  $Y$ , then  $\Delta dc(k)$  is  $Z$

where  $X$ ,  $Y$  and  $Z$  are the fuzzy variable for  $e(k)$ ,  $\Delta e(k)$  and  $\Delta dc(k)$  respectively

The rule table for the designed fuzzy controller is given in the Table 3.1 (N Senthil Kumar, 2007). The element in the first row and first column means that If error is NB, and change in error is NB then output is NB.

Table 3.1 Fuzzy Rule

**Error**

	<b>NB</b>	<b>NS</b>	<b>Z</b>	<b>PS</b>	<b>PB</b>
<b>NB</b>	NB	NB	NB	NS	Z
<b>NS</b>	NB	NB	NS	Z	PS
<b>Z</b>	NB	NS	Z	PS	PB
<b>PS</b>	NS	Z	PS	PB	PB
<b>PB</b>	Z	PS	PB	PB	PB

**Change in Error**

The reverse process of fuzzification is called defuzzification. The linguistic variables are converted in to a numerical variable. As the weighted sum method is considered to be the best well-known defuzzification method, it is utilized in the present model.

The defuzzified output is the duty cycle  $dc(k)$ . The change in duty cycle  $\Delta dc(k)$  can be obtained by adding the pervious duty cycle  $pdc(k)$  with the duty cycle  $dc(k)$  which is given in equation . Figure 3.5: Change in Duty cycle (output)

$$\Delta dc(k) = dc(k) + pdc(k) \quad (3.3)$$

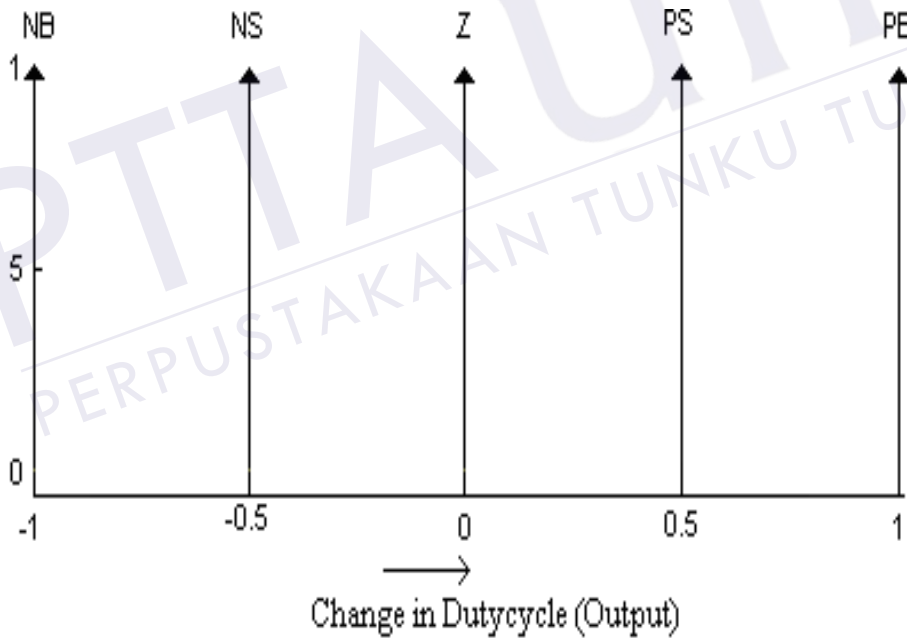


Figure 3.5: Change in Duty cycle (output)



### 3.3 Fuzzy Logic Toolbox

There are five primary graphical user interface (GUI) tools for building, editing and observing fuzzy inference systems in the toolbox:-

- Fuzzy Inference System (FIS) editor
- Membership Function editor
- Rule Editor
- Rule Viewer
- Surface Viewer

These GUI are dynamically linked and if the changes make to the FIS to the one of the toolbox, the effect can be seen in other GUIs. In addition to these five primary GUIs, the toolbox includes the graphical ANFIS Editor GUI, which is used for building and analyzing Sugeno-types adaptive neural fuzzy inference systems. (J.-S. Roger Jan, 1997)



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